23. TECHNICAL RISK ANALYSIS

IDENTIFICATION, ASSESSMENT, AND MITIGATION OF TECHNICAL RISKS

Key objectives of this feasibility study are:

1. Identify all of the technology challenges
2. Define the R&D needed to ensure that all critical components have an acceptable risk by the start of the final/detailed design phase

The major systems and components have been reviewed and the associated technology, design and engineering, and manufacturing risks assessed. The criteria for identifying and assessing these technical risks are discussed below. The assessment of the technical risks is based on in-house expertise and information from key members of the accelerator technology community.

Our goal for the R&D program is that all critical technologies reach the following Technology Maturity Levels (TML) by specific phases of the project development:

- TML Low to Medium by CD0, identification of mission need and beginning of conceptual design phase
- TML Medium to High by CD1, approved baseline and start of the detailed design phase
- TML High by start of the fabrication phase

Reaching these levels of technology maturity means reduced development risk, which translates into lower cost, schedule, and performance risks. Table 23-1 summarizes the results of the risk identification and qualitative assessment to-date and does not reflect the implementation of the risk reduction plans discussed later. Risk analysis will be ongoing throughout the project to monitor the status and progress of the risk reduction effort.

Table 23-1 Summary of the technical risk assessment

Item	Risk Factors[1]			Comments[3]
	R&D [2]	D&E[2]	Man.[2]	
RF photocathode gun	M	H	M	Warm copper RF photocathode gun demonstrated for low operation rate. D&E effort to operate reliably at high rate.
Photocathode	M	M	M	Recent results indicate good lifetime for Cs_2Te at high vacuum.
Photocathode laser	M	M	L	Laser pulse needs high temporal and amplitude stability.
Flat beam	M	L	L	Uses demonstrated technique with standard optics.
SC linacs	M	M	M	Uses SoA SC RF cavities based on TESLA TTF; some different parameters; much higher cryogenics loads.
Beam spreader section	L	M	L	Uses some specialized magnets based on experience. Tight geometry poses D&E challenge.
HGHG FELs	M	M	M	Successful proof-of-principle experiment in IR region promising for the generation of higher energy photons.
Deflecting cavities	H	H/M	M	Uses SoA SC RF cavities. Stringent requirements for stability, HOM and LOM damping.
Lattice magnets	L	L	L	Uses standard water-cooled electromagnets.
Undulators	M	H/M	H/M	Trade between permanent and SC undulators is still open: performance vs. risks. May use several different undulators.
Beamline optics	M	M	L	SoA optics with some different parameters for pulse compression.
Beam dump	L	L	L	Similar to existing beam dumps.
Diagnostics and instrumentation	L	M	L	Use of demonstrated techniques with some new requirements for measurement of beam tilt.
Synchronization	H	H	M	Tight requirements for x-ray pulses, electron bunches, and pump lasers.
Pump lasers	M	M	L	Tight synchronization required with deflecting cavities.
Control systems	L	M	L	Faster acquisition rates than ALS. Important to efficient commissioning and operations.
Low-level RF systems	M	M	L	Adjustable tuners save power. Some development required using standard techniques.
Vacuum systems	L	L	L	Similar to existing designs.

Notes:
1. The risk assessment reflects the present status of major components
2. R&D: Research and Development, D&E: Design & Engineering, Man: Manufacturing
   The criteria for the assigned risk factors are:
   H (HIGH): Concepts and/or prototypes need to be developed.
   M (MEDIUM): Similar components or subsystems have been successfully demonstrated or require some extrapolations from existing designs.
   L (LOW): Subsystems and components are essentially identical to existing and proven designs.
3. Details are presented in the text.

Specific risk mitigation plans are being developed and implemented for all the high- and medium-risk items. Several key components need extensive R&D. A number of research institutions are involved in parallel technology development programs, and participation in several of these efforts has begun. Where necessary, additional and distinct R&D efforts are proposed to meet specific requirements. Our design trade studies and analyses support these technology development activities in allocating resources in the most effective manner, to increase the probability of a successful project that meets the user needs with realistic cost and schedule.

If the basic technology is available but there is risk stemming from the advanced application of the technology multiple design approaches will be carried until a decision point is reached. If the primary risk is in the manufacturing area, multiple vendors will be carried until one proves the capability to produce the element on time in the quantity required. Rigorous acceptance testing of individual assemblies (lasers, RF power supplies, magnets, instrumentation, etc) will help to minimize these risks.

Integration is a significant risk for our machine because successful operation requires the critical coupling of different elements (lasers, RF subsystems, optics, etc). Interface and integration issues will be identified and fully integrated before the hardware/software is shipped for integration with other subsystems. Adequate commissioning time is also essential.

RF photocathode gun

Experiments at the A0 photoinjector at the Fermilab have already demonstrated that RF photocathode guns can produce electron beams with high intensity and low emittance for a repetition rate in the range of 10 to 100 Hz. The required gun must operate reliably at a significantly higher repetition rate of ~10 kHz. Control of space charge effects, thermal emittance, quantum efficiency, cavity thermal design, and overall systems reliability are significant challenges. Early results are encouraging; but, additional R&D is required to develop a design that meets the full requirements.

The gun design has a significant impact on the achievable beam current and emittance, and because of its critical importance in defining the photon beam flux and pulse duration, the engineering and design of the photocathode gun is classified as a high-risk item.

To mitigate risk factors the following actions are being pursued:

1. Participation in the experimental program and development of the FNPL photoinjector at Fermilab.
2. Active involvement in other photocathode RF gun experiments.
3. In-house design of a high-gradient, high-duty RF photocathode gun.

Our assessment is that, with additional R&D, there is a high probability of successful design and construction of a photoinjector with the parameters specified. Preliminary results are very encouraging and indicate that the requirements can be achieved at a repetition rate of 10 kHz using a reliable design with adequate safety margins. If the baseline concept does not achieve the required emittance, beam collimation may provide sufficient beam quality.

Deflecting cavities

R&D on superconducting deflecting cavities is on-going at Fermilab, KEK, and Cornell University. The Fermilab group has designed, fabricated and tested a single cell cavity, a five-cell cavity, and a thirteen-cell cavity. These cavities are designed to achieve a 5 MV/m deflecting electric field at 3.9 GHz, at a low rep rate of 5 Hz, and low duty cycle of 0.7%. The single cell cavity test has already achieved 9.5 MV/m deflecting gradient with Q_o of $1x10^9$, while the five-cell cavity has achieved 1.5 MV/m deflecting gradient with Q_o of $2x10^9$. Additional R&D and design and engineering is required to achieve the specified 8.5 MV deflecting voltage for CW operations. Additionally, there is a need to investigate and resolve several technical issues including parasitic mode damping, multipacting suppression, and input power coupling, and thus these components are considered a high risk item.

A preliminary cavity design for a 7-cell cavity has been completed using the computer simulation codes MAFIA and URMEL. Further investigations including a 3D MAFIA model of the RF coupler and analysis of its effects on the parasitic modes are in progress. Collaborations with Fermilab, TJNAF, DESY, and ACCEL GmbH have been initiated. Based on the preliminary data, this effort is judged to have a high probability of success, further details are presented in section 8-Superconducting RF.

Undulators

Since the undulator trade studies are still to be completed, our discussion of technical risks is generic rather than specific to a baseline design. Technical risks are driven by the challenging requirements for tight machining tolerances, tunable magnetic field strength ranging, long length, tight beam control and demanding instrumentation. Conventional permanent magnet undulators may provide a maximum magnetic field of ~1.0 T. To achieve higher undulator magnetic fields, a superconducting short period undulator is being considered. ACCEL Instruments GmbH and the Karlsruhe Research Center have developed a first test device of a superconducting in-vacuum undulator and are now developing a prototype to resolve a number of identified issues including manufacturing and instrumentation. The results are encouraging; but significant R&D is required to develop a practical a full-length, short period superconducting undulator. While less of a technical challenge, a permanent magnet short period long undulator still faces the design and manufacturing issues: tight mechanical tolerances, thermal environmental control, beam position monitoring, alignment stability, and radiation dose management.

Synchronization

The accurate timing of the femtosecond x-ray probe pulse with respect to the experimental pump laser that excites the processes in the sample under study is critical for the investigation of structural dynamics in the femtosecond regime. This requires that the compressed x-ray pulse and the external laser be synchronized to approximately 50 fs. Our overall strategy is to lock all laser signals to a common laser master oscillator and derive all RF signals it. Jitter reduction arising from the hard x-ray pulse compression scheme gives a significant advantage. Details are presented in Chapter 19-Synchronization.

The design and engineering challenges include:

- Stabilizing several laser oscillators to the laser master oscillator
- Stable distribution of RF signals derived from the master oscillator, throughout the machine
- Mechanical stability of RF pickups, cables, and connectors
- Drift and timing jitter of the RF photocathode laser
- Phase and amplitude jitter in the pulsed RF gun systems

Synchronization is considered to be high risk because of the stringent requirements and the design and engineering challenges.

Superconducting linacs

An active R&D effort is proceeding that includes extensive simulations and analytical studies of (i) collective effects including HOM damping and multipacting suppression, (ii) input power coupler design, and (iii) cryogenic systems. Collaborations with Fermilab, TJNAF, DESY, and ACCEL GmbH have been initiated. Although the TESLA superconducting cavity appears well suited to our requirements, we carry the CEBAF upgrade module as a viable alternative. Indications are that requirements will be achieved with the proposed plan.